

# **Comparison between different methods for viscosity Measurements**

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## **ABSTRACT**

Although high accuracy of viscosity measurement can be achieved by using viscometers, the method is tedious since it takes long-times, large volume of the samples and needs many precautions. These disadvantageous may cause many problems with the small volume samples such as the biomaterials. Two other measuring methods for viscosity measurements were tried and results were compared with that obtained by the glass viscometer. The methods compared here are Coaxial-Cylinder method and ultrasonic pulse echo method. From the results of measurement for ten kinds of oils samples with different densities, it was revealed that the differences of the average mean values of measurements were within  $\pm 0.07$  % for the glass viscometer and Coaxial-Cylinder measuring methods. The ultrasonic pulse echo method differs from that measured using glass viscometer by 0.01% in the range of 1.4 to 8.6 m.Pa.s and 0.2 % in the range of 17.6 mPa.s kinematic viscosity. Using the longitudinal ultrasonic velocity data, the ultrasonic absorption ( $\alpha$ ), adiabatic compressibility ( $\beta_a$ ) and specific acoustic impedance ( $Z$ ) are derived and tabulated.

## **Key Words:**

Kinematic viscosity, dynamitic viscosity, ultrasonic viscosity, ultrasonic parameters.

## INTRODUCTION

Viscosity is defined as the resistance per unit area of a fluid to deformation or to flow. The flow properties of liquids can be divided into three main groups (i) Newtonian; (ii) Non-Newtonian, time dependent (iii) Non-Newtonian, time independent. The viscosity of a Newtonian liquid is constant and independent of the applied shear rate (shear stress). The relation between the applied shear rate and the obtained shear stress is constant over the whole shear rate range. Liquids which show Newtonian flow behavior are often simple, single-phase liquids and solutions of liquids with low molecular weights [1].

The capillary method is simple to operate and precise in its results but suffers from the disadvantage that the rate of shear varies from zero at the centre of the capillary to a maximum at the wall. Thus, with asymmetric particles a viscosity determination in an ostwald viscometer could cover states of orientation and the measured viscosity, although reproducible, would have little significance [2] especially for the colloidal fluids. The glass viscometers should be selected to give flow times in excess of ca.100s, otherwise a kinetic energy correction is necessary.

Many studies have been done on measuring viscosity of fluids by using different techniques such as measuring viscosity using piezoelectric response voltage [3], ultrasonic [4].

Blitz [4] reported that the propagation of shear ultrasonic waves in low and high viscosity fluids is governed by the viscosity of these fluids. He found a correlation between the shear wave velocity, density, angular frequency and the ultrasonic absorption coefficient.

The ultrasonic techniques due to their simplicity and accuracy are being most widely applied in the study of liquid state, the most complicated amongst the three states of matter.

Ultrasonic velocity and absorption measurements have proved to be useful in dealing with the problems of structure of liquids and interaction between the molecules. Ultrasonic pulse-echo method is in wide spread use for these measurements.

Ultrasonic velocity in a liquid system is conditioned by the state of molecular properties of the system [5-8]. In addition to temperature, the ultrasonic velocity in a liquid system is responsive to viscosity as well [9].

The aim of this work is to compare three methods we mentioned and choose an easy, suitable, rapid method with associated uncertainty to measure the viscosity of oils needed for calibration of different types of viscometers.

## **EXPERIMENTAL WORK THEORY AND METHODS**

### ***Measuring the kinematics viscosity***

The measurements of the kinematics viscosity was carried out using glass viscometer by filling the viscometer with the oil and maintained at a thermostatic bath which connected with a cooled unit to maintain the temperature stable during the measurements, according to the capillary viscometer method [D445,IP71][ASTM]. The uncertainty of the measurements found to be  $\pm 0.4$  mPa.s in the range from 1 mPa.s to 20 mPa.s and  $\pm 1$  mPa.s till 40000 mPa.s.

### ***Measuring the dynamic viscosity***

The dynamic viscosity of the different oils was measured using coaxial cylinders viscometer namely (Bohlin controlled stress Rheometers, Gloucestershire, UK). The rheometer has a constant torque motor which works by a drive up systems. The coaxial cup and Bob having diameter of 25mm [DIN 53019]. The torque of the rotating system and angular velocity are related to the shear stress and the shear rate as follows:

$$\text{Shear stress} = C_1 \cdot \text{torque} \quad (1)$$

$$\text{Shear rate} = C_2 \cdot \text{angular velocity} \quad (2)$$

and

$$\text{Viscosity} = \text{Shear stress} / \text{Shear rate} \quad (3)$$

$$C_1 = \frac{1}{2\pi r_a^2 h} \quad C_2 = \frac{2r_i^2 r_o^2}{r_a^2 (r_o^2 - r_i^2)}$$

Where  $r_i$  = inner radius  
 $r_o$  = outer radius  
 $h$  = Height of the cylinder  
 $r_a = (r_i + r_o)/2$

The background errors were resulted from the friction between the rotating parts of the measuring system were eliminated by designing the instrument with a geometry enables all the moving parts to rotate on air bearing system so that friction will be neglected.

The shear stress vs. shear rate relation was fitted to the ideal Newtonian system and the viscosity coefficient was calculated and used through out this research all over the studied range. All viscosity measurements were done isothermally 25 °C. The uncertainty of measurements are found to be  $\pm 0.4$  mPa.s in the range from 1 mPa.s to 20 mPa.s and  $\pm 4$  mPa.s till 40000 mPa.s.

The values of the ten oils under study were verified by using Bohlin rheometer coaxial cylinders having a 25 mm diameter bob and the diameter of the cup is proportion to the bob size as defined by the standard (DIN 53019).

### ***Measuring the ultrasonic viscosity***

Ultrasonic techniques have been widely used for different of types of investigation [10]. In pulse echo method, a short sinusoidal electrical

wave activates the ultrasonic transducer. The transducer then produces sound wave train into the liquid inside the cell. This cell is made up of stainless steel, which avoids any chemical reactions between the chemicals and the cell. Some advantages of this method are that the sound velocity can be measured at the same time as the attenuation. Polarized shear waves may be used as well as longitudinal waves, and a wide range of sound frequency may be employed.

Using an oscilloscope (60 MHz time base oscilloscope, Philips, Netherlands) direct measurement of the time required for the pulses to travel twice the length of the specimen is possible, which allows immediate calculation of the ultrasonic wave velocity as given in the following equation:

$$v = \frac{2L}{\Delta t} \quad (4)$$

Where L is the liquid length and  $\Delta t$  is the time interval.

The velocity measurements using this method were carried out at a nominal frequency of 4 MHz (central frequency of 0.7 MHz and band width of 1.4 MHz) at temperature of 25 °C. The estimated accuracy of the velocity measurement is about 0.6 %.

The ultrasonic attenuation and ultrasonic viscosity are given in the form;

$$\alpha = \frac{20}{2L} \log (A_n / A_{n+1}) \quad (5)$$

$$\eta = \frac{\rho \alpha v^3}{26.3 f^2} \quad (6)$$

Where  $A_n / A_{n+1}$  is the ratio between two successive echoes  $A_n$ ,  $A_{n+1}$ ,  $\rho$  is the density of the oil and  $f$  is the ultrasonic frequency. The uncertainty of

the measurements of ultrasonic attenuation and viscosity are  $\pm 0.01$  dB/cm and  $\pm 0.03$  mPa.s respectively.

The experiment was performed over ten oil samples at different densities and single temperature 25 °C. Each experiment was repeated three times and through three days consecutively, and the median was chosen as an end result.

## RESULTS AND DISCUSSIONS:

Table 1 summarize the results of the viscosity of the studied oils at different densities with the three different method, glass viscometer method (kinematics viscosity), Coaxial-Cylinder method (dynamics viscosity) and ultrasonic pulse echo method (ultrasonic viscosity). We are going to focus our attention to compare the dynamics viscosity data and that of ultrasonic viscosity with those obtained by kinematics viscosity.

Table 1: The density ( $\rho$ ), the kinematic viscosity ( $\eta_k$ ), the dynamic viscosity ( $\eta_d$ ) and the ultrasonic viscosity ( $\eta_{us}$ ) of oils samples.

Sample No	$\rho$ (gm/cm <sup>3</sup> )	$\eta_k$ (mPa.s)	$\eta_d$ (mPa.s)	$\eta_{us}$ (mPa.s)
1	0.753	1.4	1.6	1.442
2	0.775	2.2	2.4	2.200
3	0.821	3.8	4.4	3.830
4	0.816	8.6	8.8	8.756
5	0.858	17.6	20.5	21.044
6		67.7	72.6	---
7		537.4	577.1	---
8		1108.7	1187.7	---
9		5072.9	5389.8	---
10		37304.6	40881	---

### ***Dynamics results***

The dynamic viscosity of the oil samples, whose kinematic viscosity are known, were measured isothermally at a fixed temperature of 25°C and the results were recorded and fitted to the Newtonian, power-law and Bingham's models depending on the behavior of each sample when subjected to various shear stresses. Oils found to follow Newtonian behavior and the other have a tendency to follow Bingham's model depending on the yield stress of the oils.

Figure 1 represents the behavior of the investigated of ten oil in terms of the applied shear stress and resultant shear rate. The trend line of each correlation was calculated and the equation of the relation for each oil sample was investigated. The correlation-equation of oil samples numbers 5, 6, 7, 8 and 9 (Table 1) follows the ideal Newtonian flow model. While oil samples 1, 2, 3, 4, and 10 have a slight tendency to follow Bingham flow model. This can be attributed to the yield stress for each oil sample [1].

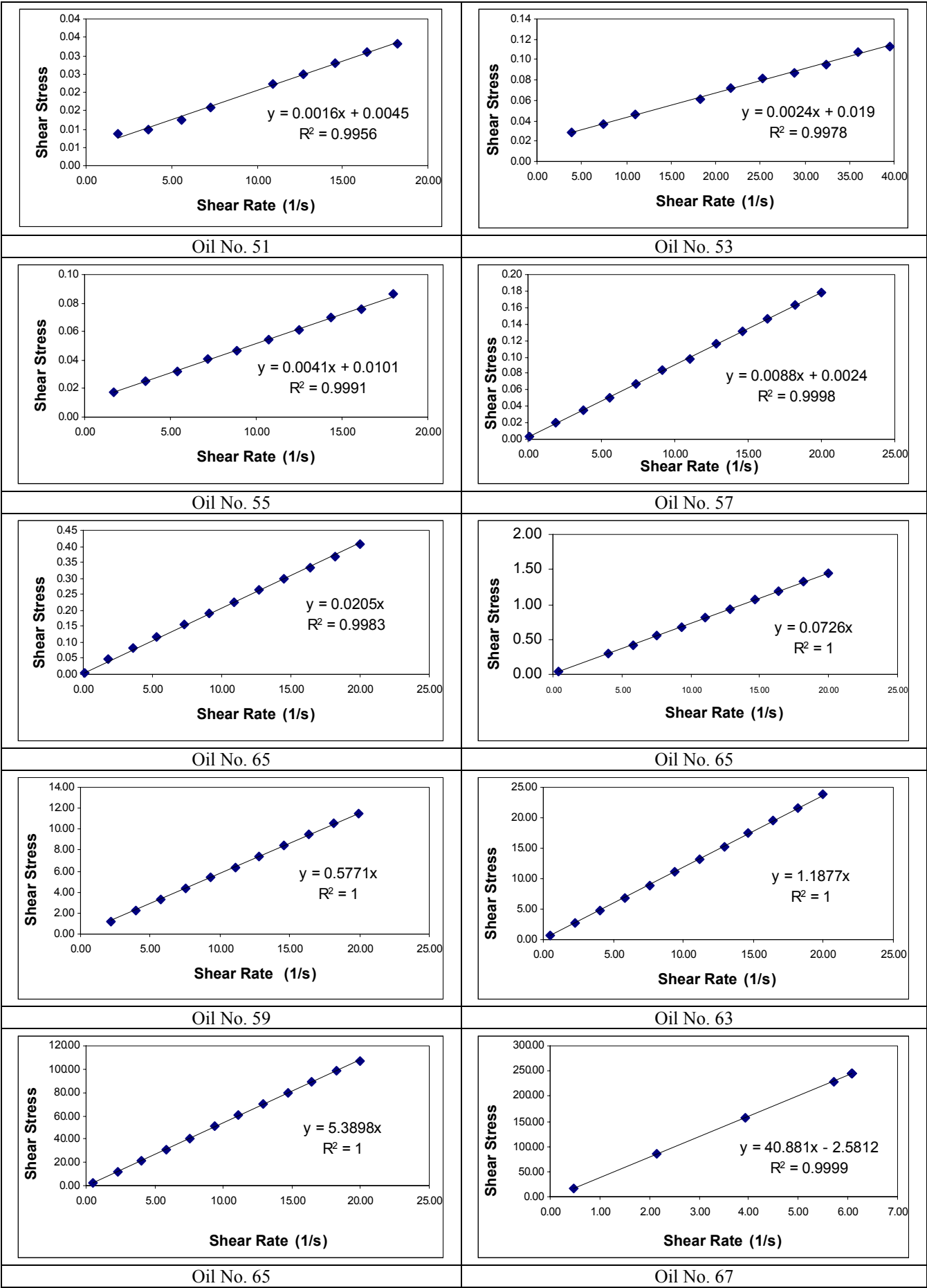


Figure (1) :Rheograms of ten oils (shear stress vs shear rate)



### ***Ultrasonic results***

Ultrasonic velocity ( $V_1$ ), ultrasonic absorption ( $\alpha$ ) and ultrasonic viscosity ( $\eta$ ) of oils are summarized in Table 2. Figure 2 shows the variation of ultrasonic viscosity with density. The increase of ultrasonic viscosity with density indicates a strong molecular interaction between oils molecules. It may be seen from the data that the ultrasonic velocity, ultrasonic absorption and ultrasonic viscosity are quite different for different densities, while density of oils covers only a very small range.

Using the measured data of ultrasonic velocity, various parameters such as adiabatic compressibility ( $\beta_a$ ) and specific acoustic impedance ( $Z$ ) were computed with the help of following equations [11].

$$\beta_a = \rho^{-1} v_1^{-2} \quad (7)$$

$$Z = \rho v_1 \quad (8)$$

The calculated data are given in Table 2. An observation of this table one can show that  $\beta_a$  is decreased from 0.021 cm/dy to 0.008 cm/dy while the ultrasonic velocity increases from 799 m/s to 1241 m/s. It may further be noted that where adiabatic compressibility or ultrasonic velocity alone is an undecided parameter, both together characterize the oils very well.

To correlate the characteristics of oils and ultrasonic velocity, the acoustic impedance ( $Z$ ) is determined. The change in compressibility and acoustic impedance appear to reflect the dominance of ultrasonic absorption over volume changes. The increase of density of oils samples from 0.751 to 0.858 gm/cm<sup>3</sup> to some extent is being set off by an increase in acoustic impedance and a decrease in compressibility. The uncertainty of the measurements of adiabatic compressibility and acoustic impedance are within  $\pm 0.05$  (cm/dy) and  $\pm 0.2$  (gm/cm<sup>2</sup>s), respectively.

A further discussion of the ultrasonic experimental results is much more difficult for the time being because of the lack of information about their molecular content.

It is clear from Table 1 that good agreement between the measurements of the dynamic viscosity ( $\eta_d$ ) and the kinematics viscosity ( $\eta_k$ ) over whole the studied range of density with mean value within 0.07%. However, excellent agreement between the ultrasonic viscosity ( $\eta_u$ ) and the kinematic viscosity has been performed in the range of density from 0.753 to 0.816 ( $\text{gm/cm}^3$ ) with mean value of 0.01% and 0.2 % of the density of 0.858 ( $\text{gm/cm}^3$ ). Afifi has expected the opinion that the lack of agreement between the ultrasonic and kinematic viscosity may refer to the difference in behavior between the ultrasonic absorption coefficient in comparison with ultrasonic viscosity, which is very clear in samples number 4 and 5 as in Table 2.

Table 2: Density ( $\rho$ ), ultrasonic velocity ( $V_l$ ), ultrasonic absorption ( $\alpha$ ), viscosity ( $\eta$ ), adiabatic compressibility ( $\beta_a$ ) and acoustic impedance of oil samples.

Sample No	$\rho$ ( $\text{gm/cm}^3$ )	$V_l$ (m/s)	$\alpha$ (dB/cm)	$\eta$ m.Pa.s	$\beta_a$ (cm/dy)	$Z*10^4$ ( $\text{gm.cm}^{-2}\text{s}^{-1}$ )
1	0.753	799	1.58	1.442	0.021	6
2	0.775	929	1.49	2.200	0.015	7.20
3	0.821	1043	1.73	3.830	0.011	8.56
4	0.816	1136	3.08	8.756	0.009	9.27
5	0.858	1241	5.40	21.044	0.008	10.65

It should be noted that the ultrasonic viscosity is a little different from that measured dynamically.  $\eta_d$  involves macroscopic displacements in the

order of  $\mu\text{m}$ , whereby chains reptate as a whole through the network. By comparison, the ultrasonic wave is a small disturbance with a typical magnitude in the  $\text{\AA}$  range that cannot dismantle the molecules; therefore ultrasonic viscosity relates to small-scale mobility of short segments between the oil molecules. Whilst  $\eta_d$  is mainly associated to the molecular weight,  $\eta_u$  is governed by the chemical nature and the morphology of the repeat units and by the distance between the oil molecules.

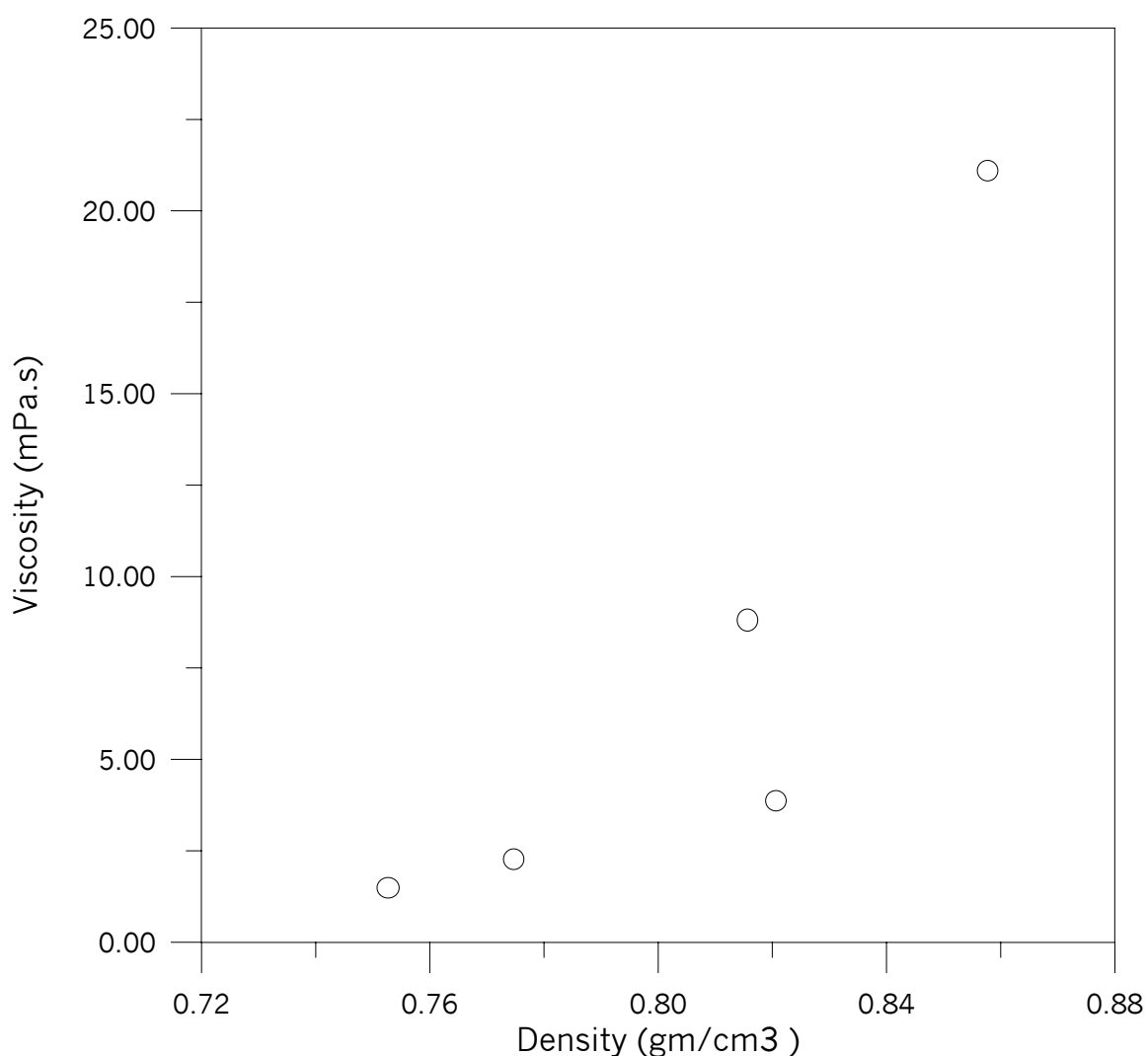


Figure 2: Variation of ultrasonic viscosity with the density of oil samples

## **Conclusion:**

The viscosity measured by capillary glass, Coaxial-Cylinder rheometer ultrasonic pulse echo method showed a good correlation and can be applied industrially. This will add the calibration of viscometers in industry. From the ultrasonic results obtained, it is of interest to conclude that the ultrasonic parameters are very suitable as characterizing parameters for oils in the range mentioned. The pulse echo method has the advantage of its indestructive nature along with its ease of operation. By applying the three techniques in industry there are three benefits: (i) saving time, (ii) saving energy and cost, (iii) required measurement accuracy. More extensive studies will be carried out to cover the other rheological systems and to evaluate the uncertainty budget of the results of all three techniques used.

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